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(54) **PILOT SIGNAL TRANSMISSION METHOD AND RADIO COMMUNICATION APPARATUS**

(71) Applicant: **NEC CORPORATION**, Tokyo (JP)

(72) Inventors: **Takamichi Inoue**, Tokyo (JP); **Yoshikazu Kakura**, Tokyo (JP)

(73) Assignee: **NEC CORPORATION**, Tokyo (JP)

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Related U.S. Application Data

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H04J 13/00 (2011.01)
(Continued)

(52) **U.S. Cl.**
CPC ***H04W 28/20*** (2013.01); ***H04J 13/0077*** (2013.01); ***H04L 5/0048*** (2013.01);
(Continued)

(58) **Field of Classification Search**
CPC H04B 2201/70701; H04J 13/0059; H04J 13/0077; H04L 5/0007; H04L 5/0048; H04L 27/2613; H04W 28/10
USPC 370/310, 343, 342, 335, 329, 328; 455/450
See application file for complete search history.

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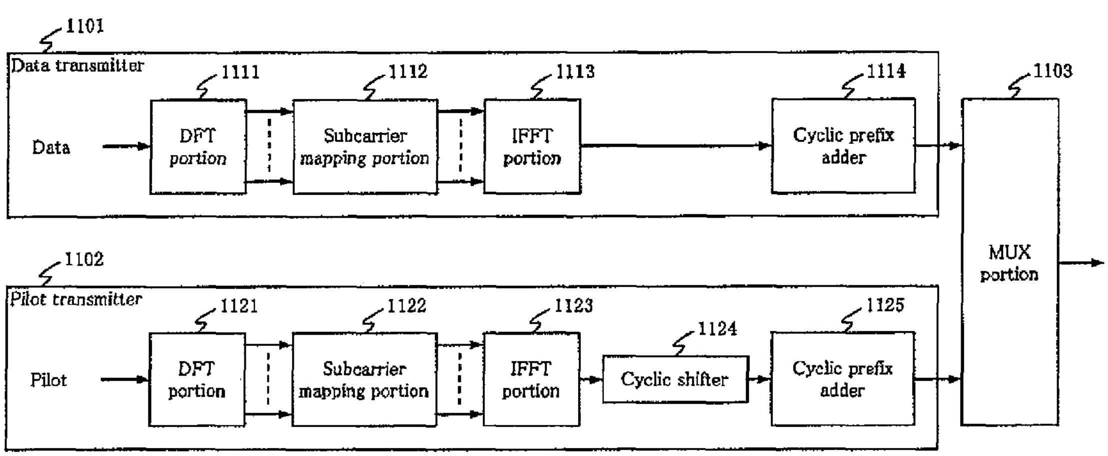
Primary Examiner — Chi H Pham
Assistant Examiner — Robert Lopata
(74) *Attorney, Agent, or Firm* — Sughrue Mion, PLLC

(57) **ABSTRACT**

In a radio communication system, transmission of CAZAC sequences as the pilot signal sequences by using code division multiplexing as at least one of user multiplexing schemes, is done by dividing a system band as a frequency band usable in the system into frequency blocks B1 and B2 having bandwidths W1 and W2, generating the pilot signals of the frequency blocks B1 and B2 with a single carrier, using the pilot signal sequences having sequence lengths L1 and L2 corresponding to frequency blocks B1 and B2 respectively; and, transmitting the generated pilot signals as the pilot signals corresponding individual users, with multicarriers using an arbitrary number of frequency blocks among the plural frequency blocks.

18 Claims, 15 Drawing Sheets



(51) **Int. Cl.**
H04L 5/00 (2006.01)
H04L 27/26 (2006.01)

(52) **U.S. Cl.**
CPC .. ***H04L27/2613*** (2013.01); *H04B 2201/70701* (2013.01); *H04J 13/0059* (2013.01); *H04L 5/0007* (2013.01)

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Fig. 1

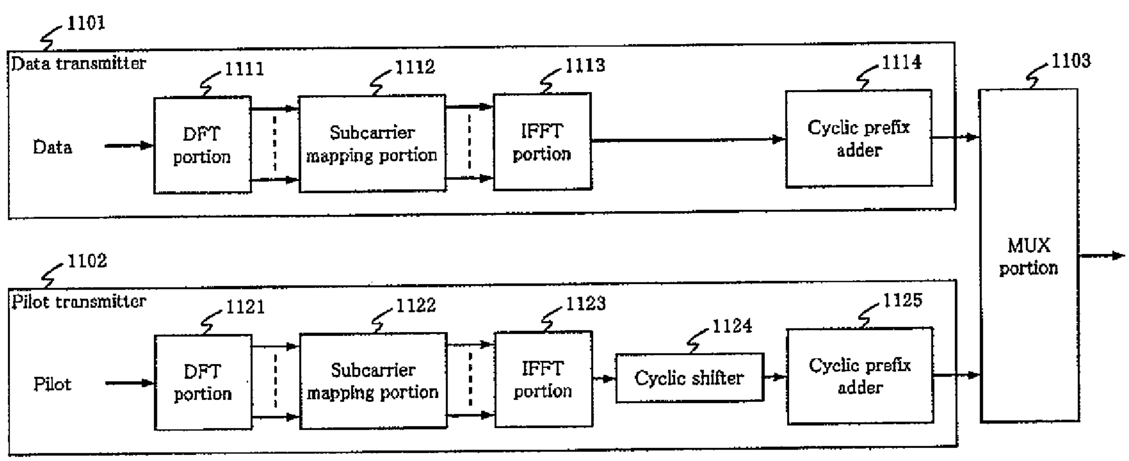

1101
Data transmitter
1111
1112
1113
1114
1103
Data
DFT portion
Subcarrier mapping portion
IFFT portion
Cyclic prefix adder
MUX portion
1102
Pilot transmitter
1121
1122
1123
1124
1125
Pilot
DFT portion
Subcarrier mapping portion
IFFT portion
Cyclic shifter
Cyclic prefix adder

Fig. 2

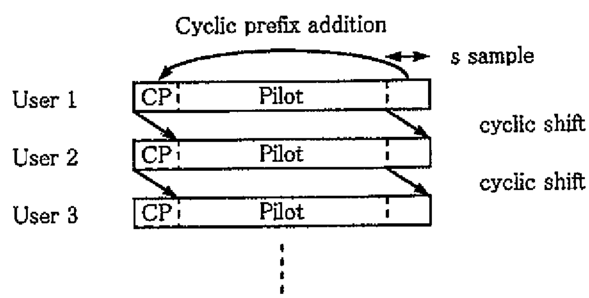

Cyclic prefix addition
s sample
User 1
CP
Pilot
cyclic shift
User 2
CP
Pilot
cyclic shift
User 3
CP
Pilot

Fig. 3

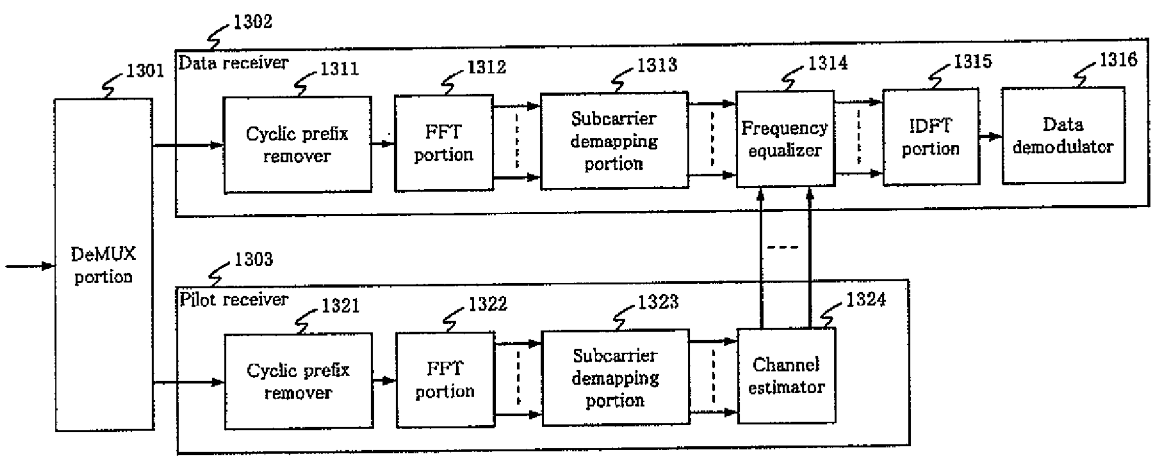

1302
Data receiver
1301
1311
1312
1313
1314
1315
1316
Cyclic prefix remover
FFT portion
Subcarrier demapping portion
Frequency equalizer
IDFT portion
Data demodulator
DeMUX portion
1303
Pilot receiver
1321
1322
1323
1324
Cyclic prefix remover
FFT portion
Subcarrier demapping portion
Channel estimator

Fig. 4

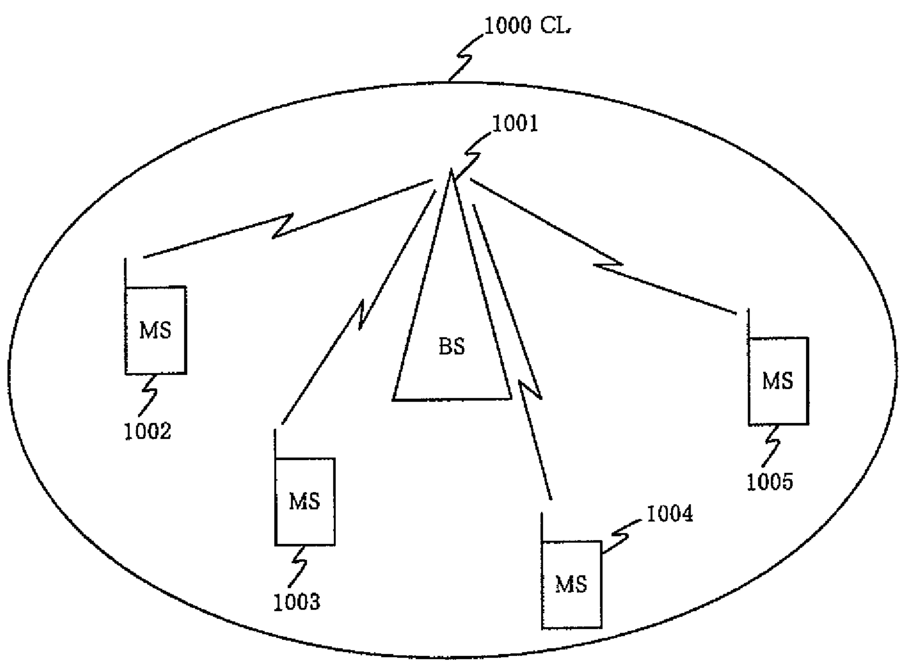


Fig. 5

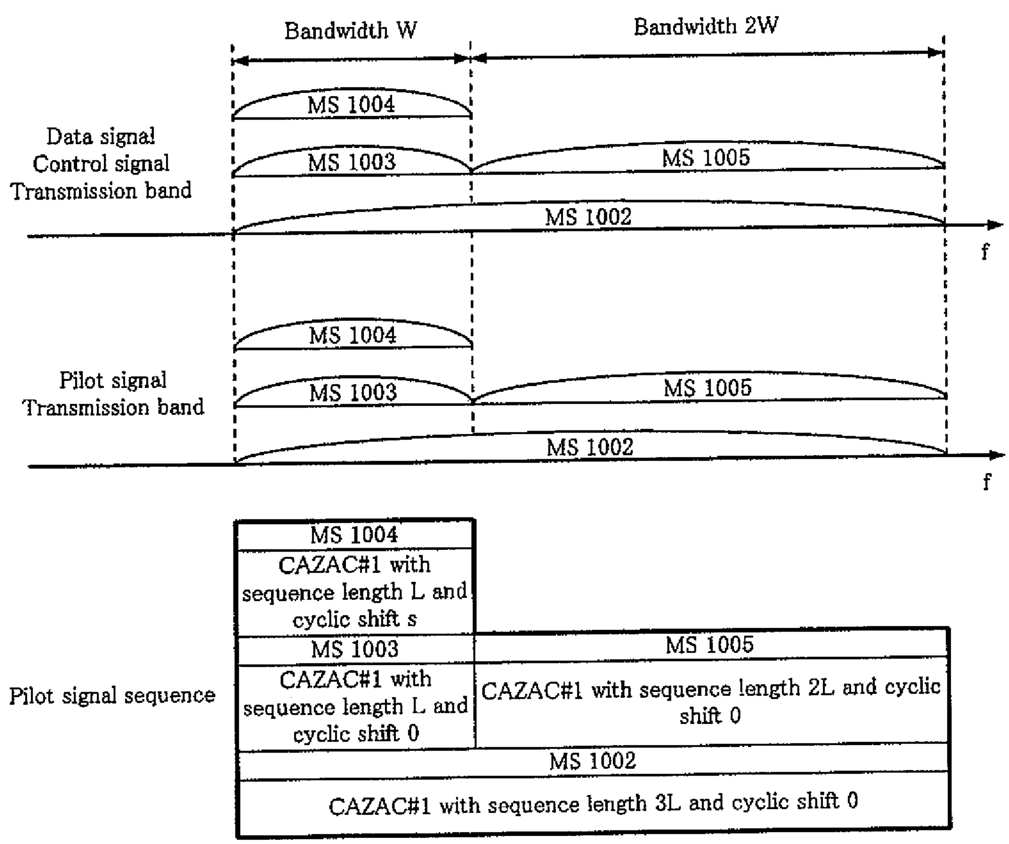

Bandwidth W
Bandwidth 2W
MS 1004
Data signal
Control signal
Transmission band
MS 1003
MS 1005
MS 1002
f
MS 1004
Pilot signal
Transmission band
MS 1003
MS 1005
MS 1002
f
Pilot signal sequence
MS 1004
CAZAC#1 with sequence length L and cyclic shift s
MS 1003
CAZAC#1 with sequence length L and cyclic shift 0
MS 1005
CAZAC#1 with sequence length 2L and cyclic shift 0
MS 1002
CAZAC#1 with sequence length 3L and cyclic shift 0

Fig. 6

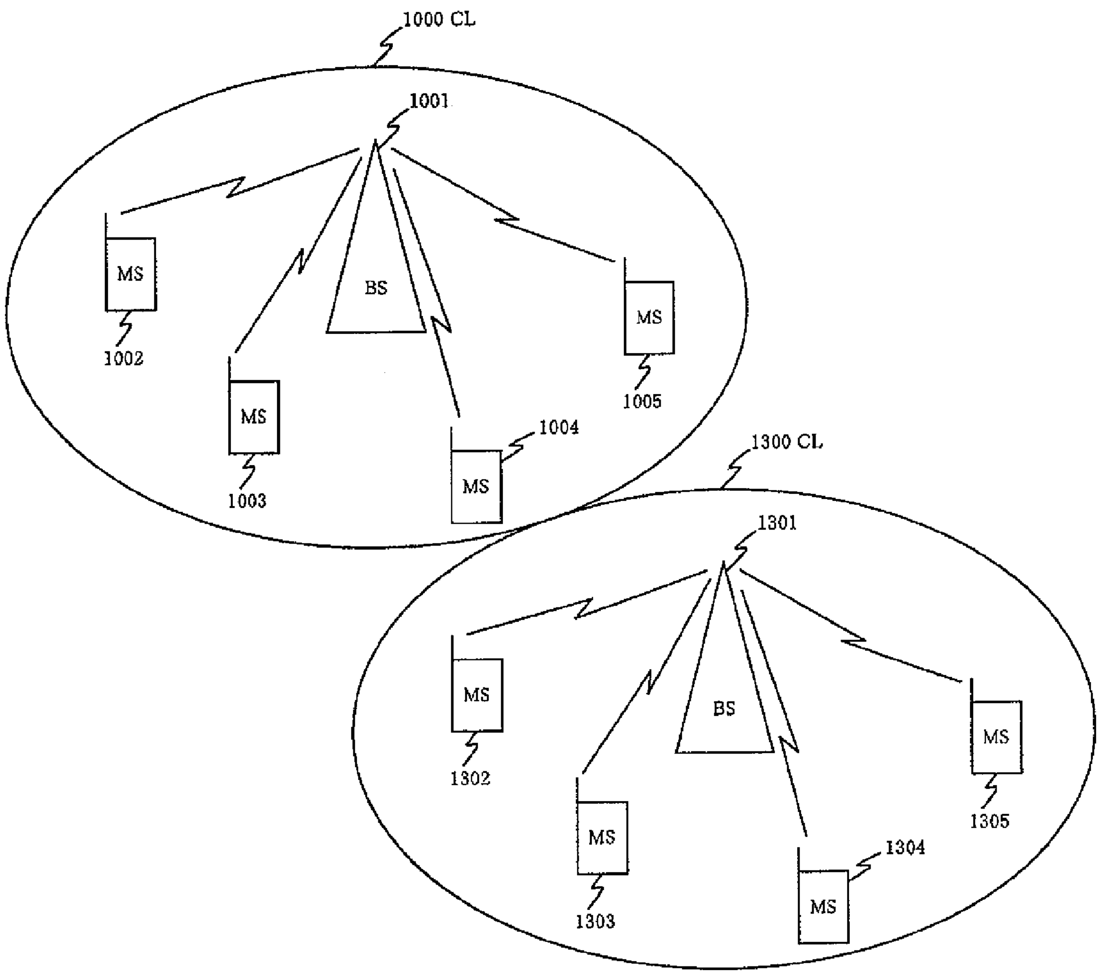

1000 CL
1001
BS
MS
1002
MS
1003
MS
1004
MS
1005
1300 CL
1301
BS
MS
1302
MS
1303
MS
1304
MS
1305

Fig. 7

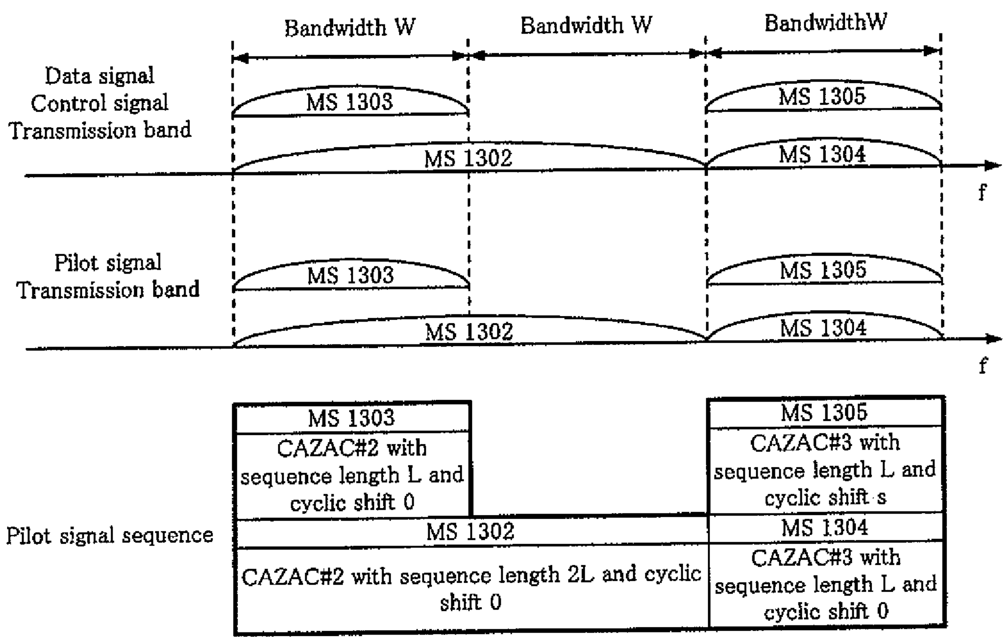

Bandwidth W
Bandwidth W
BandwidthW
Data signal
Control signal
Transmission band
MS 1303
MS 1305
MS 1302
MS 1304
f
Pilot signal
Transmission band
MS 1303
MS 1305
MS 1302
MS 1304
f
Pilot signal sequence
MS 1303
CAZAC#2 with sequence length L and cyclic shift 0
MS 1305
CAZAC#3 with sequence length L and cyclic shift s
MS 1302
CAZAC#2 with sequence length 2L and cyclic shift 0
MS 1304
CAZAC#3 with sequence length L and cyclic shift 0

Fig. 8

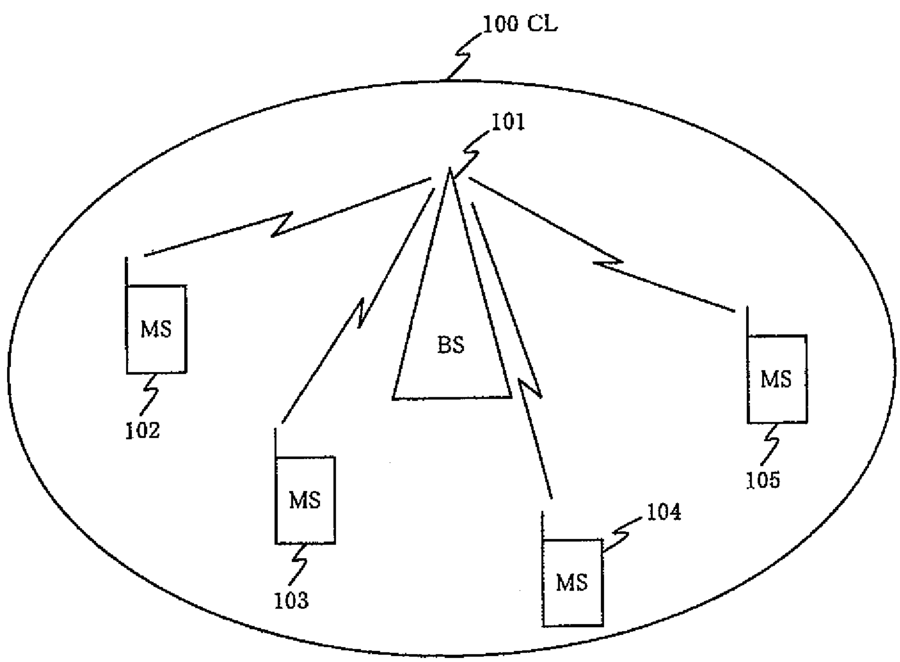
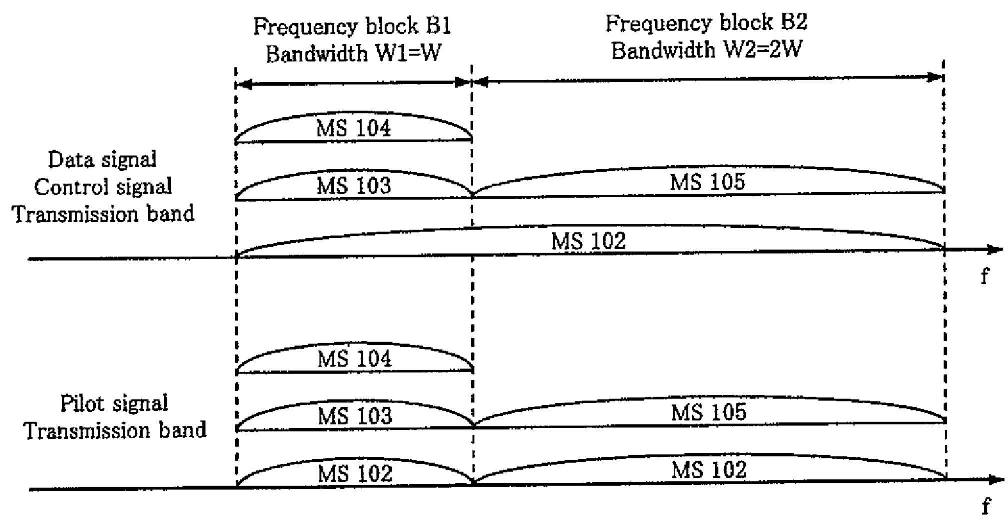


Fig. 9



Pilot signal sequence

MS 104	
CAZAC#1 with sequence length L and cyclic shift 2s	
MS 103	MS 105
CAZAC#1 with sequence length L and cyclic shift s	CAZAC#1 with sequence length 2L and cyclic shift s
MS 102	MS 102
CAZAC#1 with sequence length L and cyclic shift 0	CAZAC#1 with sequence length 2L and cyclic shift 0

Fig. 10

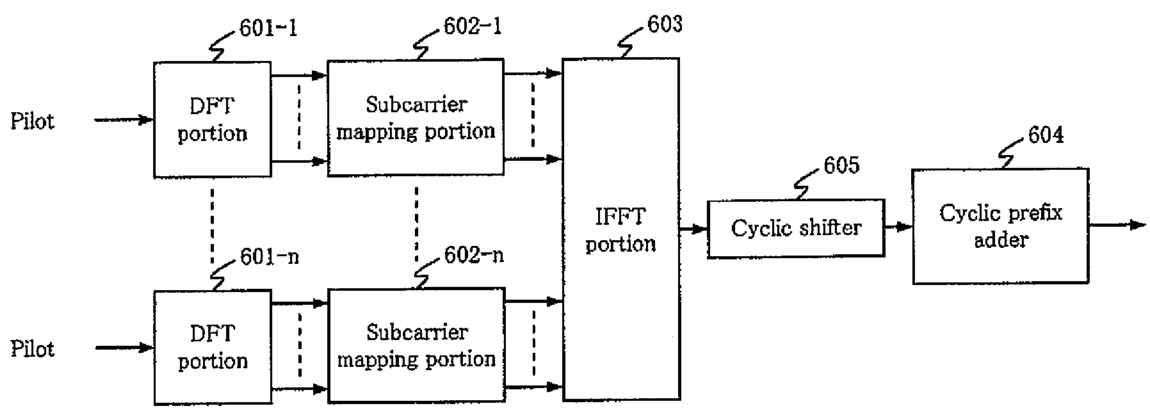
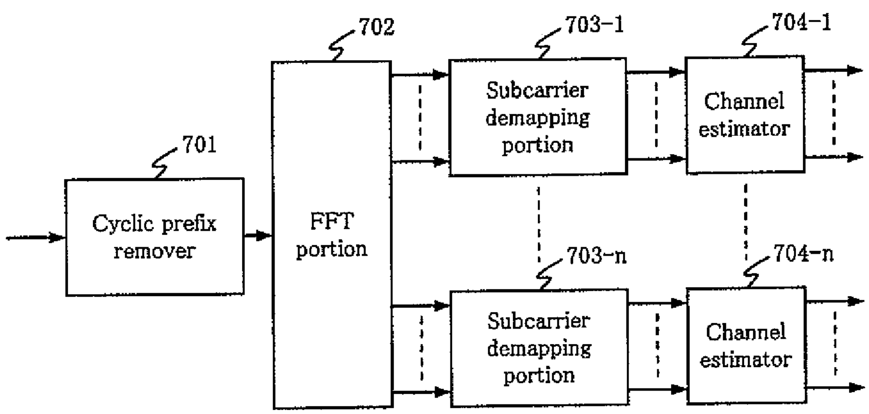

601-1
602-1
603
Pilot
DFT portion
Subcarrier mapping portion
604
605
IFFT portion
Cyclic shifter
Cyclic prefix adder
601-n
602-n
Pilot
DFT portion
Subcarrier mapping portion

Fig. 11



701
Cyclic prefix remover
702
FFT portion
703-1
Subcarrier demapping portion
703-n
Subcarrier demapping portion
704-1
Channel estimator
704-n
Channel estimator

Fig. 12

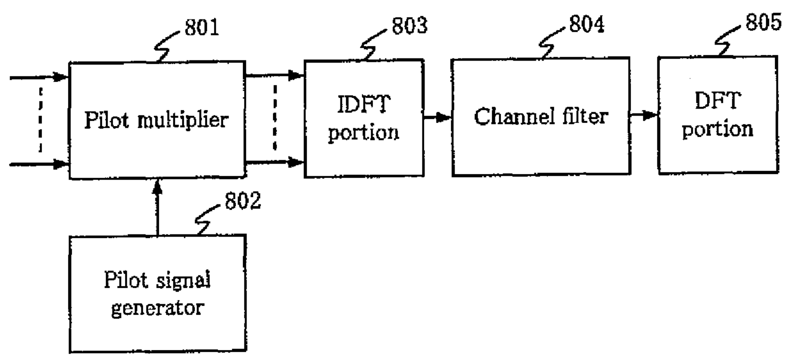

801
803
804
805
Pilot multiplier
IDFT portion
Channel filter
DFT portion
802
Pilot signal generator

Fig. 13

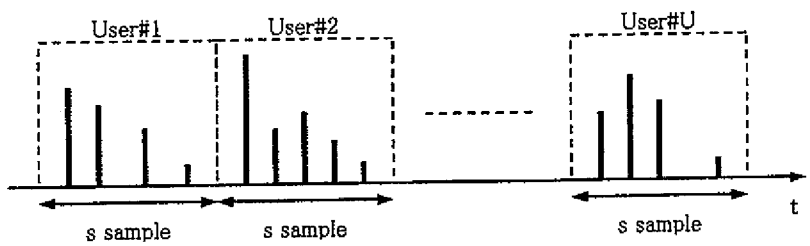


Fig. 14

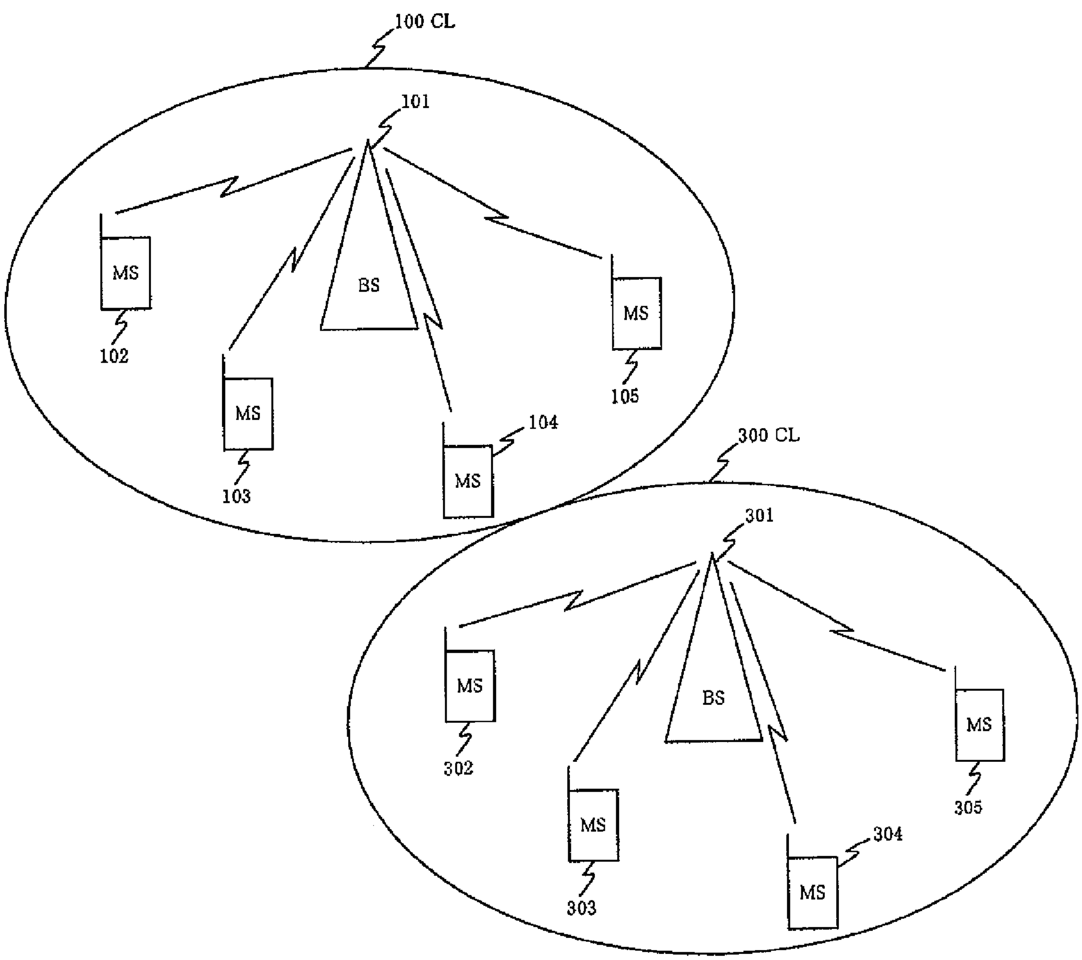
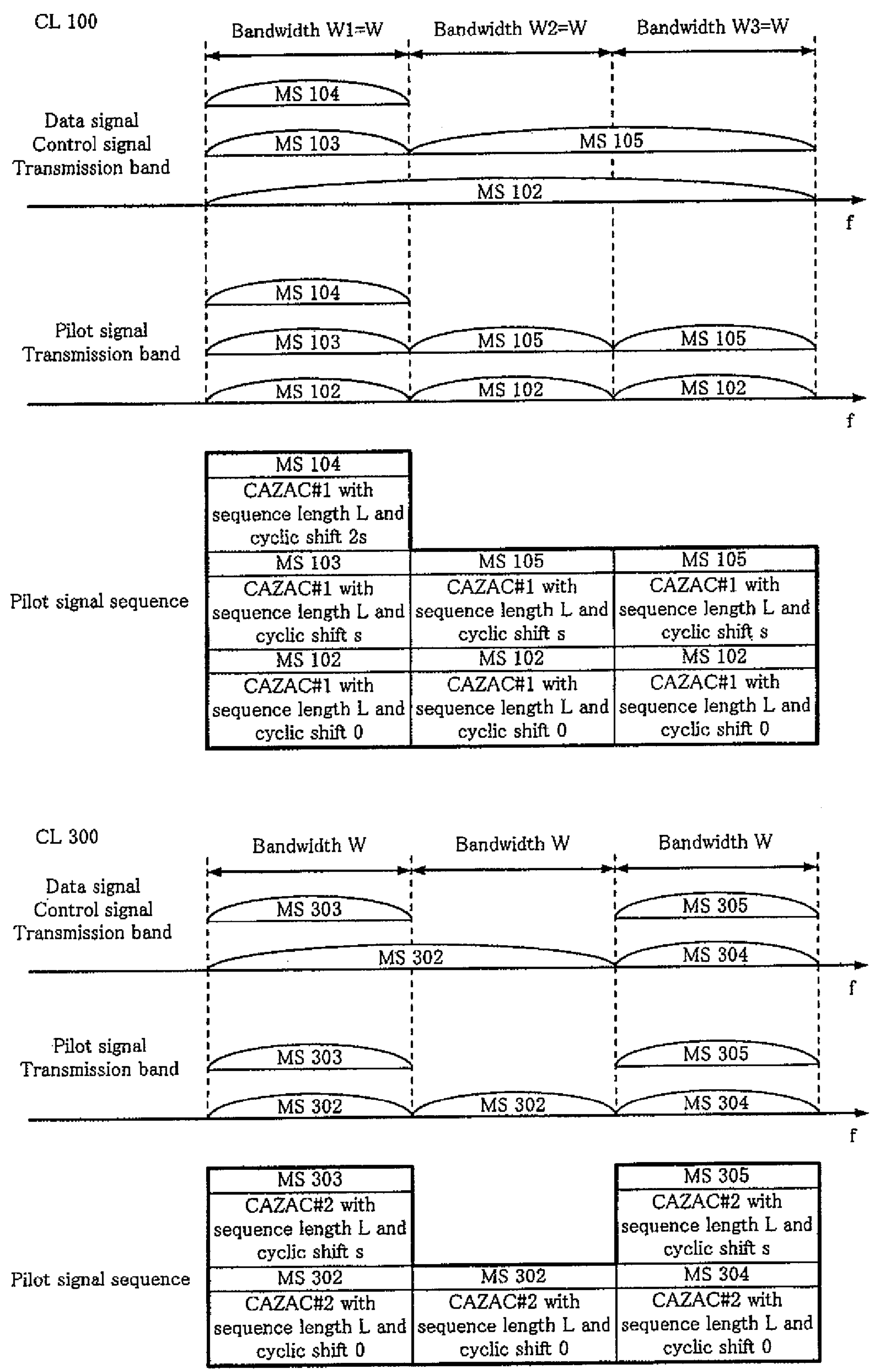

100 CL
101
BS
MS
102
MS
103
MS
104
MS
105
300 CL
301
BS
MS
302
MS
303
MS
304
MS
305

Fig. 15


CL 100
Bandwidth W1=W
Bandwidth W2=W
Bandwidth W3=W
Data signal
Control signal
Transmission band
MS 104
MS 103
MS 105
MS 102
f
Pilot signal
Transmission band
MS 104
MS 103
MS 105
MS 105
MS 102
MS 102
MS 102
f
Pilot signal sequence
MS 104
CAZAC#1 with sequence length L and cyclic shift 2s
MS 103
CAZAC#1 with sequence length L and cyclic shift s
MS 105
CAZAC#1 with sequence length L and cyclic shift s
MS 105
CAZAC#1 with sequence length L and cyclic shift s
MS 102
CAZAC#1 with sequence length L and cyclic shift 0
MS 102
CAZAC#1 with sequence length L and cyclic shift 0
MS 102
CAZAC#1 with sequence length L and cyclic shift 0
CL 300
Bandwidth W
Bandwidth W
Bandwidth W
Data signal
Control signal
Transmission band
MS 303
MS 305
MS 302
MS 304
f
Pilot signal
Transmission band
MS 303
MS 305
MS 302
MS 302
MS 304
f
Pilot signal sequence
MS 303
CAZAC#2 with sequence length L and cyclic shift s
MS 305
CAZAC#2 with sequence length L and cyclic shift s
MS 302
CAZAC#2 with sequence length L and cyclic shift 0
MS 302
CAZAC#2 with sequence length L and cyclic shift 0
MS 304
CAZAC#2 with sequence length L and cyclic shift 0

PILOT SIGNAL TRANSMISSION METHOD AND RADIO COMMUNICATION APPARATUS

CROSS-REFERENCE TO RELATED APPLICATIONS

This is a continuation of U.S. application Ser. No. 13/352,968, filed Jan. 18, 2012, which is a continuation of U.S. application Ser. No. 12/298,098 filed Oct. 22, 2008, which is based on 371 National Stage Application No. PCT/JP2007/051051 filed on Jan. 24, 2007, which claims priority from Japanese Patent Application No. 2006-120432 filed on Apr. 25, 2006, the disclosures of which are incorporated herein by reference in their entirety.

TECHNICAL FIELD

The present invention relates to a radio communication system, and in particular relates to a pilot signal transmission method and radio communication apparatus that transmit a pilot signal in the uplink.

BACKGROUND ART

Recently, Beyond 3G has been developed as the next-generation radio network which can establish seamless and safety connection between a plurality of radio communication systems including third generation mobile communications (3G), wireless LANs and fourth generation mobile communications (4G). As the uplink transmission scheme for the Beyond 3G, use of a single carrier transmission scheme is considered (e.g., see literature '3GPP, "TR25.814 v1.2.2" March 2006'(which will be referred to hereinbelow as literature 1)).

FIG. **1** is a diagram showing a configuration of a transmitter based on a single carrier transmission scheme described in literature 1.

The transmitter shown in FIG. **1** includes data transmitter **1101**, pilot transmitter **1102**, MUX portion **1103** for multiplexing these outputs.

Further, data transmitter **1101** includes DFT (Discrete Fourier Transformation) portion **1111**, subcarrier mapping portion **1112**, IFFT (Inverse Fast Fourier Transformation) portion **1113** and cyclic prefix adder **1114**.

Data transmitter **1101** shown in FIG. **1** operates as follows:

First,

data made up of

$$N_{Tx\_d} \qquad \text{[Math 1]}$$

symbols,

is transformed into a frequency-domain signal by applying DFT at

$$N_{Tx\_d} \qquad \text{[Math 2]}$$

points to the data at DFT portion **1111**. Then, in subcarrier mapping portion **1112** the frequency-domain signal is mapped onto sub-carriers (by inserting '0' into unused subcarriers

to form data of subcarriers amounting to

$$N_{FFT\_d}). \qquad \text{[Math 3]}$$

Then, the frequency-domain signal after the subcarrier mapping is

transformed into time-domain signal by applying IFFT at

$$N_{FFT\_d} \qquad \text{[Math 4]}$$

points to the data at IFFT **1113**. Finally, in cyclic prefix adder **1114**, the data is added with a cyclic prefix to be transmitted.

FIG. **2** is a diagram showing how a cyclic prefix is added in cyclic prefix adder **1114** shown in FIG. **1**.

Cyclic prefix addition at cyclic prefix adder **1114** shown in FIG. **1** is to copy the rear part of the block to the front end of the block as shown in FIG. **2**.

It should be noted that a cyclic prefix is inserted in order to efficiently perform frequency-domain equalization on the receiver side. The cyclic prefix length is preferably set so as not to exceed the maximum delay time of the delay path in the channel.

Next, a configuration of a typical receiver corresponding to the transmitter shown in FIG. **1** will be described.

FIG. **3** is a diagram showing a configuration of a typical receiver corresponding to the transmitter shown in FIG. **1**.

The receiver shown in FIG. **3** includes: DeMUX portion **1301** for separating the signal transmitted from the transmitter shown in FIG. **1** into a data signal and a pilot signal; data receiver **1302**; and pilot receiver **1303**.

Further, data receiver **1302** is comprised of cyclic prefix remover **1311**, FFT (Fast Fourier Transformation) portion **1312**, subcarrier demapping portion **1313**, frequency equalizer **1314**, IDFT (Inverse Discrete Fourier Transformation) portion **1315** and data demodulator **1316**.

Data receiver **1302** shown in FIG. **3** operates as follows:

First, at cyclic prefix remover **1311**, the cyclic prefix is removed from the received signal. Then,

the data is transformed into a frequency signal by applying FFT at

$$N_{FFT\_d} \qquad \text{[Math5]}$$

points in FFT portion **1312**. Then, the signal is demapped into subcarriers used by each user at subcarrier demapping portion **1313**. After demapping, the signal is subjected to frequency-domain equalization at frequency equalizer **1314**, based on the channel estimate obtained by channel estimator **1324** (described later) of pilot signal receiver **1303**. Then,

the signal is transformed into time-domain signal by applying IDFT at

$$N_{Tx\_d} \qquad \text{[Math6]}$$

points in IDFT portion **1315**, and then the received data is demodulated at data demodulator **1316**.

Next, the uplink pilot signal and a user multiplexing method will be described.

Recently, as a pilot signal sequence, CAZAC (Constant Amplitude Zero Auto-Correlation) sequences have drawn attention. For example, as one of CAZAC sequences, the Zadoff-Chu sequence expressed by formula 1 can be considered (e.g., see a literature 'B. M. Povic, "Generalized Chirp—Like Polyphase Sequences with Optimum Correlation Properties," IEEE Transactions on Information Theory, Vol. 38, No. 4, pp 1406-1409, July 1992).

[Math 7]

$$c_k(n) = \begin{cases} \exp\left[\frac{j2\pi k}{L}\left(\frac{n^2}{2}+n\right)\right] & \text{when the sequence length } L \text{ is even} \\ \exp\left[\frac{j2\pi k}{L}\left(n\frac{n+1}{2}+n\right)\right] & \text{when the sequence length } L \text{ is odd} \end{cases} \qquad \text{(Formula 1)}$$

A CAZAC sequence is a sequence that has a constant amplitude in both time and frequency domains and produces self-correlation values of '0' other than when the phase difference is '0'. Since the sequence is constant in amplitude in the time domain, it is possible to suppress the PAPR (Peak to

Average Power Ratio), and since the sequence is also constant in amplitude in the frequency domain, the sequence is suitable for channel estimation in the frequency domain. Further, since the sequence has an advantage of being suitable for timing detection of the received signal because it has perfect self-correlation characteristics, the sequence has drawn attention as a pilot sequence that is suitable for single carrier transmission, which is the access scheme for uplink of Beyond 3G.

As the user multiplexing method when CAZAC sequences are used as the pilot signal sequences for uplink, Code Division Multiplexing (CDM) has been proposed (e.g., see literature '3GPP, R1-051062, Texas Instruments "On Uplink Pilot in EUTRA SC-OFDMA", October 2005').

In CDM of the pilot signals, all the users use CAZAC sequences of an identical sequence length added with a cyclic shift unique to each user. If the cyclic shift time is taken to be equal to or longer than the expected maximum delay, the pilot signals of all the users under the multipath environment can be made orthogonal to one another. This is feasible based on the property that the self-correlation value of a CAZAC sequence constantly becomes '0' other than when the phase difference is '0'.

The transmitter and receiver of a pilot signal when the pilot signal undergoes CDM will be described with reference to FIGS. **1** and **3**. Since the basic configuration and operation of pilot transmitter **1102** is the same as data transmitter **1101**, the points different from data transmitter **1101** will be described.

To begin with, the numbers of points for DFT portion **1121** and for IFFT portion **1123** are

$$N_{Tx\_p}, N_{FFT\_p} \quad \text{[Math8]}$$

(in literature 1, these are defined as

$$N_{Tx\_p}=N_{Tx\_d}/2, N_{FFT\_p}=N_{FFT\_d}/2). \quad \text{[Math 9]}$$

When user multiplexing of pilot signals is performed by CDM, in order to separate the users from each other at the receiver, cyclic shift portion **1124** performs a cyclic shift unique to the user. A cyclic shift is a shift whereby the pilot signal sequence is handled like a ring, and the pilot signal sequence is reentered from the last end into the front end as shown in FIG. **2**. The amount of the cyclic shift for each user is preferably equal to or greater than the maximum delay of the delay path, or the cyclic prefix length. Finally, the cyclic prefix is added at cyclic prefix adder **1125**, and the generated data signal and the pilot signal are time-multiplexed through MUX portion **1103** to be transmitted.

Next, pilot receiver **1303** will be described.

In pilot receiver **1303**, the data signal and the pilot signal are separated from each other by DeMUX portion **1301**, then the cyclic prefix is removed by cyclic prefix remover **1321**. Then, the pilot signal

is subjected to FFT at

$$N_{FFT\_p} \quad \text{[Math 10]}$$

points by FFT portion **1322**, so as to be transformed into the pilot signal in the frequency domain. Then, subcarrier demapping is performed at subcarrier demapping portion **1323**, thereafter, channel estimation is performed by channel estimator **1324**. The channel estimate for each user is output to frequency equalizer **1314** of data receiver **1302**.

When CAZAC sequences are used in a cellar system, the cross-correlation characteristic is also important. In view of inter-cell interference suppression, it is preferred that a group of sequences that yield small cross-correlation values are allotted as the pilot signal sequences for neighboring cells. The cross-correlation characteristics of a Zadoff-Chu sequence greatly depend on the individual sequence. For example, when the sequence length L of a Zadoff-Chu sequence includes a prime or a large prime, it presents excellent cross-correlation characteristics (a low cross-correlation value). On the other hand, when it is a composite number composed of small primes only, the cross-correlation greatly degrades (the cross-correlation value contains a large value). Specifically, the sequence length L of Zadoff-Chu sequences is a prime, the cross-correlation value between arbitrary Zadoff-Chu sequences is considered to be kept constant at

$$(1/L)^{1/2} \quad \text{[Math 11]}$$

(see non-patent document 3, for example).

In Beyond 3G, it is assumed that the transmission bandwidths of data signals and control signals differ from one user to another. Accordingly, the pilot signal used for demodulation of the data signal and control signal differs in transmission bandwidth for every user, hence it is necessary to multiplex the plot signals of users different in transmission bandwidth.

FIG. **4** is a diagram showing one configurational example a conventional mobile radio system.

In the mobile radio system shown in FIG. **4**, constituted of BS**1001** as a base station and CL**1000** as a service area formed by BS**1001**, a plurality of mobile stations MS**1002**-**1005** for performing communications with the BS**1001** are provided.

FIG. **5** is a diagram showing frequency blocks used by the users in the mobile radio system shown in FIG. **4** and one example of pilot signal sequences used for the individual users.

As shown in FIG. **5**, when the data signal or control signal is transmitted with a single carrier using a frequency block having continuous frequencies, the pilot signal is also transmitted with a signal carrier using the same frequency block as that of the data signal or control signal.

In a case where CDM is used to multiplex the pilot signal, when, in FIG. **5** for example, the bandwidths of the signals transmitted by MS**1002**-**1005** are 3W, W, W and 2W (W is a predetermined bandwidth), CAZAC sequences having a sequence length of 3L, L, L and 2L corresponding to respective bandwidths will be used as the pilot signal sequences.

In this case, there is the problem that the pilot signals for the users who perform pilot signals using different frequency blocks of continuous frequencies will not become orthogonal. The reason is that the sequence lengths of the pilot signals are not the same between the users who use different frequency blocks.

FIG. **6** is a diagram showing another configurational example of a conventional mobile radio system.

In the mobile radio system shown in FIG. **6**, constituted of BS**1001** and **1301** as base stations and CL**1000** and CL**1300** as service areas formed by BS**1001** and BS**1301**, a plurality of mobile stations MS**1002**-**1005** and MS**1302**-**1305** for performing communications with BS**1001** and BS**1301** respectively are provided.

FIG. **7** is a diagram showing frequency blocks used by the users in CL**1300** of the mobile radio system shown in FIG. **6** and one example of pilot signal sequences used by the individual users. Here, the frequency blocks used by the users in CL**1000** and the pilot signal sequences used by the individual users are assumed to be the same as those shown in FIG. **5**.

Remarking the frequency blocks used in adjacent cells, for example, MS**1003**, or MS**1004**, and MS**1303** have the same bandwidth, so that it is possible to suppress inter-cell interference using difference CAZAC sequences. In contrast, for example, MS**1002** and MS**1302**, or MS**1002** and MS**1304** use frequency blocks different in bandwidth, hence it is impossible to suppress inter-cell interference. In other words, when CAZAC sequences used as pilot signals are different in sequence length, there is the problem that inter-cell interference cannot be suppressed. The reason is that the mutual correction characteristics between CAZAC sequences different in sequence length degrade.

DISCLOSURE OF INVENTION

In order to solve the problems described above, it is an object of the present invention to provide a pilot signal transmission method and a radio communication apparatus in a mobile radio system, whereby when CAZAC sequences are transmitted as pilot signals and CDM is used as the user multiplexing method, the pilot signals of users different in bandwidth can be made orthogonal in a cell and inter-cell interference to pilot signals from another cell can be reduced.

In order to achieve the above object, the present invention is a pilot signal transmission method for use in a radio communication system, to transmit pilot signal sequences which at least have either the first property that the self-correlation value when the phase difference is other than zero is equal to or lower than a predetermined threshold relative to the peak self-correlation value when the phase different is zero, or the second property that the cross-correlation value between the sequences that are equal in sequence length is smaller than the cross-correlation value between the sequences that are different in sequence length, by using code division multiplexing as at least one of user multiplexing schemes, comprising the steps of:

dividing a system band as a frequency band usable in the system into a plurality of frequency blocks having plural kinds of bandwidths;

generating pilot signals of said plural frequency blocks with a single carrier, using said pilot signal sequences having sequence lengths corresponding to said plural frequency blocks; and,

transmitting said generated pilot signals as the pilot signals corresponding individual users, with multicarriers using an arbitrary number of frequency blocks among said plurality of frequency blocks.

The present invention is also characterized by including the steps of:

diving the same band of all the neighboring cells into a plurality of frequency blocks having plural kinds of bandwidths; and

using different sequences among said pilot signal sequences having said sequence lengths corresponding to the bandwidths of said plural frequency blocks, between different cells that transmit pilot signals through said frequency blocks.

The present invention is also characterized by including the step of dividing said system band into a plurality of frequency blocks having an identical bandwidth.

The present invention is also characterized in that CAZAC sequences are used as said pilot signal sequences.

The present invention is also characterized by including the step of transmitting a data signal or control signal with a single carrier using said frequency blocks having continuous frequencies.

Further, in a radio communication system, a radio transmission apparatus for transmitting signals by transmitting pilot signal sequences which at least have either the first property that the self-correlation value when the phase difference is other than zero is equal to or lower than a predetermined threshold relative to the peak self-correlation value when the phase different is zero, or the second property that the cross-correlation value between the sequences that are equal in sequence length is smaller than the cross-correlation value between the sequences that are different in sequence length, while using code division multiplexing as at least one of user multiplexing schemes, is characterized by generating said pilot signal sequences having sequence lengths corresponding to plural frequency blocks having plural kinds of bandwidths into which a system band as a frequency band usable in the system is divided, generating pilot signals using said generated pilot signal sequences, with a single carrier, transmitting said generated pilot signals as the pilot signals corresponding individual users, with multicarriers using an arbitrary number of frequency blocks among said plurality of frequency blocks.

The invention is also characterized in that said pilot signal sequences having an identical sequence length is generated.

The invention is also characterized in that CAZAC sequences are generated as said pilot signal sequences.

The invention is also characterized in that a data signal or control signal is transmitted with a single carrier using said frequency blocks having continuous frequencies.

In the present invention thus constructed as above, when pilot signal sequences which at least have either the first property that the self-correlation value when the phase difference is other than zero is equal to or lower than a predetermined threshold relative to the peak self-correlation value when the phase different is zero, or the second property that the cross-correlation value between the sequences that are equal in sequence length is smaller than the cross-correlation value between the sequences that are different in sequence length, are transmitted while using code division multiplexing as at least one of user multiplexing schemes, a system band as a frequency band usable in the system is divided into a plurality of frequency blocks having plural kinds of bandwidths; pilot signals of the plural frequency blocks are generated with a single carrier, using the pilot signal sequences having sequence lengths corresponding to the plural frequency blocks; and, the generated pilot signals are transmitted as the pilot signals corresponding individual users, with multicarriers using an arbitrary number of frequency blocks among the plurality of frequency blocks.

Accordingly, all the sequence lengths for the pilot signal sequences can be made identical, hence it is possible to select sequences having good cross-correlation characteristics.

As has been described, the present invention is constructed such that, when pilot signal sequences which at least have either the first property that the self-correlation value when the phase difference is other than zero is equal to or lower than a predetermined threshold relative to the peak self-correlation value when the phase different is zero, or the second property that the cross-correlation value between the sequences that are equal in sequence length is smaller than the cross-correlation value between the sequences that are different in sequence length, are transmitted while using code division multiplexing as at least one of user multiplexing schemes, a system band as a frequency band usable in the system is divided into a plurality of frequency blocks having plural kinds of bandwidths; pilot signals of the plural frequency blocks are generated with a single carrier, using the pilot signal sequences having sequence lengths corresponding to the plural frequency blocks; and, the generated pilot signals are transmitted as the pilot signals corresponding individual users, with multicarriers using an arbitrary number of frequency blocks among the plurality of frequency blocks. Accordingly, it is possible to make the pilot signals of different users in the band orthogonal to each other and reduce inter-cell interference of pilot signals from other cells.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a diagram showing a configuration of a transmitter based on a single carrier transmission scheme shown in literature 1.

FIG. **2** is a diagram showing the manner in which cyclic prefix addition in the cyclic prefix adder shown in FIG. **1** is performed.

FIG. **3** is a diagram showing a configuration of a typical receiver that corresponds to the transmitter shown in FIG. **1**.

FIG. **4** is a diagram showing a configurational example of a conventional mobile radio system.

FIG. **5** is a diagram showing one example of frequency blocks used by users and pilot signal sequences used by individual users in the mobile radio system shown in FIG. **4**.

FIG. **6** is a diagram showing another configurational example of a conventional mobile radio system.

FIG. **7** is a diagram showing one example of frequency blocks used by users and pilot signal sequences used by individual users in the CL of the mobile radio system shown in FIG. **6**.

FIG. **8** is a diagram showing the first embodiment mode of a mobile radio system in which a radio communication apparatus of the present invention is used.

FIG. **9** is a diagram showing bands through which individual users transmit pilot signals and CAZAC sequences used thereupon in the mobile radio system shown in FIG. **8**.

FIG. **10** is a diagram showing one configurational example of a pilot signal transmitter according to the first embodiment mode of a radio communication apparatus of the present invention.

FIG. **11** is a diagram showing one configurational example of a pilot signal receiver that corresponds to the pilot signal transmitter shown in FIG. **10**.

FIG. **12** is a diagram showing one configurational example of the channel estimators shown in FIG. **11**.

FIG. **13** is a diagram showing an example of a time-domain signal obtained from the IDFT portion shown in FIG. **12**.

FIG. **14** is a diagram showing the second embodiment mode of a mobile radio system in which a radio communication apparatus of the present invention is used.

FIG. **15** is a diagram showing bands through which individual users transmit pilot signals and CAZAC sequences used thereupon in the mobile radio system shown in FIG. **14**.

BEST MODE FOR CARRYING OUT THE INVENTION

Next, the embodiment modes of the present invention will be described with reference to the drawings.

The First Embodiment Mode

FIG. **8** is a diagram showing the first embodiment mode of a mobile radio system in which a radio communication apparatus of the present invention is used.

As shown in FIG. **8**, in this mode, in BS**101** as a base station and a plurality of mobile stations MS**102**-**105** for performing communications with BS**101** in CL**100** as a service area formed by BS**101** are provided. Here, BS**101** and MS**102**-**105** are the radio communication apparatus of the present invention.

FIG. **9** is a diagram showing bands through which individual users transmit pilot signals and CAZAC sequences used thereupon in the mobile radio system shown in FIG. **8**.

As shown in FIG. **9**, the system band as the frequency band that is usable in the system is divided into frequency blocks B1 and B2. It is also assumed that every user uses a different band to transmit the data signal or control signal with a single carrier. In this case, all the users use identical CAZAC sequences having a sequence length of L1 or L2 corresponding to the frequency block bandwidth W1=W or W2=2.

Accordingly, MS**102** performs simultaneous multi-carrier transmission by using two frequency blocks B1 and B2 corresponding to CAZAC sequence lengths L1=I and L1=2L. MS**103** and MS**104** perform single carrier transmission using bandwidth W1 corresponding to CAZAC sequence length L1=L. MS**105** performs single carrier transmission using bandwidth W2 corresponding to CAZAC sequence length L2=2L. Here, the users that perform transmission through the same band use identical CAZAC sequences that are cyclically shifted by a phase unique to each user.

In this way, by unifying the bandwidth of the frequency blocks of pilot signals or by unifying CAZAC sequence length to be used, it is possible to make the users having pilot signals of different transmission bands orthogonal to each other.

FIG. **10** is a diagram showing one configurational example of a pilot signal transmitter according to the first embodiment mode of a radio communication apparatus of the present invention.

As shown in FIG. **10**, this configuration is composed of a plurality of DFT portions **601-1** to **601**-*n*, a plurality of subcarrier mapping portions **602-1** to **602**-*n*, IFFT portion **603**, cyclic prefix adder **604** and cyclic shifter **605**.

The pilot signal transmitter shown in FIG. **10** operates as follows.

First, CAZAC sequences having sequence lengths corresponding to the bandwidth of frequency blocks are inserted to DFT portions **601-1** to **601**-*n*, whereby they are transformed into frequency-domain pilot signals. Here, the number of points of DFT portions **601-1** to **601**-*n*,

$$N_{Tx\_p\_1} \sim N_{Tx\_p\_n} \quad \text{[Math 12]}$$

correspond to the sequence lengths corresponding to bandwidths of respective carriers. Here, n(n=1 to N) is the number of carries to be transmitted simultaneously.

Then, the frequency-transformed pilot signals are inserted to subcarrier mapping portions **602-1** to **602**-*n*, whereby they are subcarrier mapped. After sub-carrier mapping, the subcarrier mapped frequency-domain pilot signals

are supplied to IFFT portion **603**, where they are subjected to FFT at points

$$N_{FFT\_p} \quad \text{[Math 13]}$$

so as to be transformed into time-domain pilot signals.

Thereafter, in cyclic shifter **605**, a cyclic shift unique to the user is performed and a cyclic prefix is added in cyclic prefix adder **604**.

The thus generated pilot signals are time multiplexed over the data signal generated by the same process as in the conventional example.

The process described heretofore is the process on the transmitter side in the pilot signal transmission method of the present invention.

FIG. **11** a diagram showing one configurational example of a pilot signal receiver that corresponds to the pilot signal transmitter shown in FIG. **10**. Here, the receiver of the data has the same configuration as the conventional one, hence only the receiver of the pilot signal after the pilot signal has been separated from the data signal by a multiplexer will be shown in FIG. **11**.

The pilot signal receiver shown in FIG. **11** includes cyclic prefix remover **701**, FFT portion **702**, a plurality of subcarrier demapping portions **703-1** to **703-*n*** and a plurality of channel estimators **704-1** to **704-*n***.

The pilot signal receiver shown in FIG. **11** operates as follows.

First, the cyclic prefix is removed from the received signal in cyclic prefix remover **701**. Then,

the resultant signal is subjected to FFT at

$$N_{FFT\_p} \quad \text{[Math 14]}$$

points, by FFT portion **702** to be transformed into the received signal in the frequency domain. Thereafter, the signal is demapped to subcarriers used by the individual user by subcarrier demapping portions **703-1** to **703-*n***. After subcarrier demapping, the subcarrier-demapped frequency signals are inserted into channel estimators **704-1** to **704-*n***.

FIG. **12** is a diagram showing one configurational example of channel estimators **704-1** to **704-*n*** shown in FIG. **11**.

As shown in FIG. **12**, channel estimators **704-1** to **704-*n*** shown in FIG. **11** each include pilot multiplier **801**, pilot signal generator **802**, IDFT portion **803**, channel filter **804** and DFT portion **805**.

In pilot multiplier **801**, the subcarrier demapped, frequency-domain received signal is multiplied with the complex conjugate of the pilot signal in frequency-domain representation, generated by pilot signal generator **802**. Pilot signal generator **802** may be a memory that memorizes the pilot signal in frequency representation or a circuit that calculates based on a generation formula.

Then, the multiplied signal is processed

by IDFT portion **803** where it is subjected to IDFT at points

$$N_{Tx\_p\_n} \quad \text{[Math 15]}$$

that corresponds to the bandwidth of the frequency block, so as to be transformed into the time-domain signal.

FIG. **13** is a diagram showing an example of a time-domain signal obtained from IDFT portion **803** shown in FIG. **12**.

As shown in FIG. **13**, the signal which the impulse responses to the channels for different users shifted with respect to time, by performing cyclic shifts unique to users in cyclic shifter **605** shown in FIG. **10**.

The thus obtained impulse responses to the channels are passed through channel filter **804**, so that the impulse response to the channel corresponding to each user is obtained. The obtained impulse response of each user

is processed through DFT portion **805** so that it is subjected to DFT at points

$$N_{Tx\_p\_n}, \quad \text{[Math 16]}$$

so as to be transformed into the channel estimate in the frequency domain, which provides frequency response to the channel used for frequency equalization.

The above-described process is the process on the receiver side in the pilot signal transmission method of the present invention.

The first embodiment mode of the present invention was described by taking a case in which CAZAC sequences are transmitted as the pilot signal sequences while code division multiplexing is used as the user multiplexing method. In this case, the system band is divided into frequency blocks, and pilot signals are generated on a single carrier using the sequences that are obtained by cyclically shifting an identical pilot signal sequence having a sequence length corresponding to the bandwidth of each frequency block, and the pilot signals corresponding to each user are constructed so as to be transmitted with n multicarriers using arbitrary n frequency blocks of the frequency blocks. Accordingly, since CAZAC sequences of the same sequence length can be used for different users in the same band, it is possible to make the user pilot signals orthogonal to each other.

The Second Embodiment

FIG. **14** is a diagram showing the second embodiment mode of a mobile radio system in which a radio communication apparatus of the present invention is used.

As shown in FIG. **14**, in this mode, in BS**101** and BS**301** as base stations and a plurality of mobile stations MS**102-105** and MS**302-305** for performing communications with BS**101** and BS**301** respectively in CL**100** and CL**300** as service areas formed respectively by BS**101** and BS**301** are provided. Here, BS**101**, **301**, MS**102-105** and **302-305** are the radio communication apparatus of the present invention.

FIG. **15** is a diagram showing bands through which individual users transmit pilot signals and CAZAC sequences used thereupon in the mobile radio system shown in FIG. **14**. Here, similarly to the conventional configuration, it is assumed that data signal or control signal is transmitted with a single carrier using frequency blocks having continuous frequencies.

In the first embodiment mode, the bands through which individual users transmit their pilot signals by single carriers, are unified. In the second embodiment mode, the bands through which pilot signals are transmitted by single carriers are unified, inclusive of the users in another cell.

Accordingly, referring to FIG. **15**, MS**102** of CL**100** performs multi-carrier transmission by simultaneously transmitting three carriers (bandwidth W1=W2=W3=W) corresponding to CAZAC sequence lengths L1=L2=L3=L. MS**103** and MS**104** perform single carrier transmission using bandwidth W1 corresponding to CAZAC sequence length L1=L. MS**105** performs multi-carrier transmission by simultaneously transmitting two carriers (bandwidth W2=W3=W) corresponding to CAZAC sequence lengths L2=L3=L.

On the other hand, MS**302** of CL**300** performs multi-carrier transmission by simultaneously transmitting two carriers (bandwidth W1=W2=W) corresponding to CAZAC sequence lengths L1=L2=L. MS**303** performs single carrier transmission using bandwidth W1 corresponding to CAZAC sequence length L1=L. MS**304** and MS**305** perform single carrier transmission using bandwidth W3 corresponding to CAZAC sequence length L3=L.

As the sequences used for the pilot signals, in the same band inside the cell, the sequences that are obtained by cyclically shifting an identical CAZAC sequence by the phases unique to the users are used while in the same band of a different cell, a different CAZAC sequence is used. Since CAZAC sequences have the properties that only when sequences have the same length, there exist sequences that produce a low cross-correlation function, it is possible to unify the bandwidth of the frequency block of pilot signals in the same band of all the cells. That is, when the sequence lengths of CAZAC sequences are unified, it is possible to reduce inter-cell interference.

The pilot signal transmitter and receiver of the second embodiment mode have the same configurations as those in FIGS. **10** to **12** described in the first embodiment mode, description will be omitted.

In the second embodiment mode of the present invention, the same band of neighboring cells for neighboring service areas are divided into the same frequency blocks. The users of the different cells that transmit pilot signals through a divided frequency block, use different CAZAC sequences among the

CAZAC sequences having a sequence length corresponding to the bandwidth of the frequency block to generate pilot signals with a single carrier. The pilot signal corresponding to each user is transmitted with n multicarriers using arbitrary n frequency blocks among the frequency blocks. Accordingly, in the same band of the users in the cell and different cell, CAZAC sequences having the same sequence length can be used. As a result, it is possible to make the pilot signals inside the cell orthogonal to each other and reduce inter-cell interference.

Though the second embodiment mode was described taking a case where the same CAZAC sequence is used inside the cell for the different bands in the cell, the same effect can also be expected if different CAZAC sequences are used.

Further, though the second embodiment mode of the present invention was described taking a case where there are two service cells for service areas, it goes without saying that the same effect can also be expected in a case where there are three or more service cells.

Also, though the second embodiment mode was described taking a case where the neighboring service cells have the same system band, even when the system bands of the neighboring service cells are different from each other, the same effect can also be expected if the same band is divided into frequency blocks in the same manner.

Also, though the embodiment mode of the present invention was explained taking a case where frequency blocks have different bandwidths ($W1 \neq W2$), the same effect can be obtained when the bandwidths of frequency blocks are equal to each other ($W1=W2$).

Also, though the embodiment mode of the present invention was described taking a case where the system band is divided into three frequency blocks, the same effect can also be expected when there are two or more frequency blocks.

Also, though the embodiment mode of the present invention was described taking a case where the frequency blocks through which pilot signals are transmitted is constituted of bandwidth W and its integer multiples, the same effect can also be expected when frequency blocks not having the integer multiple of bandwidth W are included.

Also, though the embodiment mode of the present invention was described taking a case where the pilot signal of each user is transmitted with multicarriers using frequency blocks whose frequencies are continuous, the same effect can also be expected when the pilot signal is transmitted with multicarriers using frequency blocks whose frequencies are discontinuous.

Also, in the above description, BS**101**, **301** and MS**102-105** and **302-305** were described as radio communication apparatus including the above-described pilot signal transmitter and pilot signal receiver to transmit signals.

Further, the above first and second embodiment modes were described taking examples in which CAZAC sequences are used as the pilot signal sequences. A pilot signal sequence may be used, which at least has either the first property that the self-correlation value when the phase difference is other than zero, is equal to or lower than a predetermined threshold relative to the peak self-correlation value when the phase difference is zero, or the second property that the cross-correlation value between the sequences that are equal in sequence length is smaller than the cross-correlation value between the sequences that are different in sequence length. In this case, when the data signal to be demodulated has a low operational point (Eb/N0=0 to 5 dB) such as QPSK for example, if the threshold for the self-correlation value when the phase difference is other than zero is −20 dB(10%) relative to the self-correlation peak when the phase difference is zero, no degradation in characteristics will occur. However, when the data signal to be demodulated has a high operational point such as 16 QAM and 64 QAM, the threshold of the self-correlation value needs to be set at a further lower level.

What is claimed is:

1. A user equipment comprising:

a reference signal generator configured to generate a first reference signal including a sequence having a first sequence length corresponding to a first bandwidth assigned for data transmission and a second reference signal including a sequence having a second sequence length corresponding to a second bandwidth assigned for data transmission; and

a transmitter configured to transmit, in a radio communication system, from the user equipment, the first reference signal using the first bandwidth and the second reference signal using the second bandwidth.

2. The user equipment in accordance with claim **1** wherein,

the transmitter is further configured to transmit signals including a data using three or more bandwidths including the first bandwidth and the second bandwidth.

3. The user equipment in accordance with claim **1** wherein,

the transmitter is further configured to transmit signals including a data using a multi-carrier transmission of a first single carrier transmission using the first bandwidth and a second single carrier transmission using the second bandwidth.

4. The user equipment in accordance with claim **1** wherein, the first bandwidth is equal to the second bandwidth.

5. The user equipment in accordance with claim **1** wherein, the first bandwidth is different from the second bandwidth.

6. The user equipment in accordance with claim **1** wherein,

at least one of the sequence having the first sequence length and the sequence having the second sequence length is a CAZAC sequence or a cyclic shifted CAZAC sequence.

7. A radio communication system comprising a user equipment configured to transmit reference signals, the radio communication system comprising:

a reference signal generator configured to generate a first reference signal including a sequence having a first sequence length corresponding to a first bandwidth assigned for data transmission and a second reference signal including a sequence having a second sequence length corresponding to a second bandwidth assigned for data transmission; and

a transmitter configured to transmit, from the user equipment, the first reference signal using the first bandwidth and the second reference signal using the second bandwidth.

8. The radio transmission system in accordance with claim **7** wherein,

the transmitter is further configured to transmit signals including a data using three or more bandwidths including the first bandwidth and the second bandwidth.

9. The radio transmission system in accordance with claim **8** wherein,

the transmitter is further configured to transmit signals including a data using a multi-carrier transmission of a first single carrier transmission using the first bandwidth and a second single carrier transmission using the second bandwidth.

10. The radio transmission system in accordance with claim **7** wherein, the first bandwidth is equal to the second bandwidth.

11. The radio transmission system in accordance with claim **7** wherein, the first bandwidth is different from the second bandwidth.

12. The radio transmission system in accordance with claim **7** wherein,

at least one of the sequence having the first sequence length and the sequence having the second sequence length is a CAZAC sequence or a cyclic shifted CAZAC sequence.

13. A radio transmission method comprising:

generating a first reference signal including a sequence having a first sequence length corresponding to a first bandwidth assigned for data transmission and a second reference signal including a sequence having a second sequence length corresponding to a second bandwidth assigned for data transmission; and

transmitting, in a radio communication system, from a user equipment, the first reference signal using the first bandwidth and the second reference signal using the second bandwidth.

14. The radio transmission method in accordance with claim **13** wherein,

the transmitting is executed by using three or more bandwidths including the first bandwidth and the second bandwidth.

15. The radio transmission method in accordance with claim **14** wherein,

the transmitting is executed by a multi-carrier transmission of a first single carrier transmission using the first bandwidth and a second single carrier transmission using the second bandwidth.

16. The radio transmission method in accordance with claim **13** wherein, the first bandwidth is equal to the second bandwidth.

17. The radio transmission method in accordance with claim **13** wherein, the first bandwidth is different from the second bandwidth.

18. The radio transmission method in accordance with claim **13** wherein,

at least one of the sequence having the first sequence length and the sequence having the second sequence length is a CAZAC sequence or a cyclic shifted CAZAC sequence.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 9,392,492 B2
APPLICATION NO. : 14/593753
DATED : July 12, 2016
INVENTOR(S) : Takamichi Inoue and Yoshikazu Kakura

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

In the claims
Column 14, line 2: delete "claim 14" and insert --claim 13--

Signed and Sealed this
Twenty-fifth Day of October, 2016

Michelle K. Lee

Michelle K. Lee
Director of the United States Patent and Trademark Office